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The DNDC model: Development and Application in Chinese Agro-ecosystems

Prof. Dr. Jianjun Qiu

Institute of Agricultural Resources and Regional Planning, CAAS

Started cooperation with Changsheng since 1997







2 Database Establishment





Model modifications Validations Sensitivity tests

Modifications to DNDC

* Modifying cropping system:

One harvest to two or three harvests per year; Re-calibration of crop parameters, e.g. C/N, biomass.

* Improving nitrate leached module:

Directly determining fraction of nitrate leaching rate by improving desorption coefficient, water balance etc.

* Adding manure module to the original model

Modifications: water balance



Validations to DNDC



- A sequence of validation tests conducted for different cropping systems across China:
 - □ crop growth/yield,
 - □ soil climate,
 - □ soil C dynamics, and
 - □ N fluxes.

Validations to DNDC: Different cropping systems

The national farmlands are divided into six agricultural regions based mainly on their agro-climate and cropping management conditions.

The model was validated for the different cropping systems including...



Validations to DNDC: Crop growth



FP



The modeled crop growth is in line with observations

Validations to DNDC: Soil climate



Validations to DNDC: SOC dynamics



Figures a-f represent SOC dynamics in 6 agricultural regions in China (Wang et al., 2008)

Validations to DNDC: Soil CO₂ fluxes











Validations to DNDC: N₂O fluxes



Sensitivity tests: GHGs emission



Sensitivity tests: nitrate leaching loss





Publications on DNDC improvements



- Qiu Jianjun, Wang Ligang (eds). 2012. Quantified evaluation and controlling technology on Carbon & Nitrogen balance of agro-ecosystem in the region of Bohai Bay, *China Science Press*, Beijing, 2012.
- Gao Maofang. 2011. Model Simulation on Agricultural Non-point Source Nitrogen Pollution in Xiaoqinghe Watershed [D]. Chinese Academy of Agricultural Sciences Doctor Dissertation.
- Li Hu. 2009. Quantifying Analysis on Non-point Source Nitrogen Pollution in Xiaoqing River basin of Shandong Province [D]. *Chinese Academy of Agricultural Sciences Doctor Dissertation*.
- Yang Li. 2013. Mechnism and Countermeasure on C sequestration and N₂O mitigation for spring maize field in Western Liaoning[D]. *Chinese Academy of Agricultural Sciences Doctor Dissertation*.



- Site mode \longrightarrow Regional mode
- Field sampling (e.g., climate data, soil property, pH, SOC, etc.)
- Statistic data collection (e.g., crop types, tillage, fertilizer, irrigation, livestock, etc.)
- Remote sensing (e.g., crop types, land use change, etc.)



-GIS-database

What are the challenges?

- Assessments of agriculture at the national scale require the best information on spatial distribution of cropland and management practices.
- Official cropland statistics for China contain adequate information of crop types but with less accurate acreage data and coarse spatial resolution.
- Remote sensing products can provide moderate to fine spatial resolution estimates of cropland location and extent, but usually supply little information on crop type or management.
- We combined 1990 county-scale agricultural census statistics on total cropland area and sown area of 17 major crops with a fineresolution landcover map derived from 1995-96 optical remote sensing (Landsat Thematic Mapper) data to generate 0.5° resolution maps of the distribution of 47 different cropping systems for the mainland China.



We estimated that, of 1.3-million km² of cropland, approximately 60% was single-season, 30% double-season, and 10% triple-season cropping systems. Total sown area was 2.0-million km².

Cropping Systems in China





Maps of the distribution of crop rotations in China: (a) all single-crop rotations; (b) all doublecrop rotations; and (c) all triple-crop rotations. All maps are 0.5° resolution, and the grayscale refers to the land area within each gridcell that is classified in the specified rotation.



Qiu J., H. Tang, S. Frolking, et al. 2003. Combining remote sensing and ground census data to develop new maps of the distribution of cropland in China, *Geocarto International*, 18(2):3-13

Rice Cropping Systems in China

< 10

>500









Rice systems calibrated with remote sensing data



Area (km^2)

-600 - -300 -300 - -50 -50 - 50 50 - 300 300 - 800 800 - 1700

Maps of the distribution of rice crop rotations in China.

- a) The sum of above Figures a-d
- b) Landsat-derived paddy area with no distinction of single or multi-cropping
- c) The difference in areas between the Landsat analysis and this study: Figure b minus Figure a

Frolking, S., J. Qiu, S. Boles, et al. 2002. Combining remote sensing and ground census data to develop new maps of the distribution of rice agriculture in China, *Global Biogeochemical Cycles*, 16(4), 1091. doi:10.1029/2001GB001425



- Modeling SOC dynamics, GHGs emissions, and N leaching at site scale;
- Modeling impacts of SOC on Crop Yields and GHGs in China;
- Modeling impacts of management practices on GHGs emissions;
- Regional inventory of SOC, GHGs, Nbalance, N-leaching, etc.



Modeling SOC dynamics, GHGs emissions,

N leaching, etc. at site scale

Modeling SOC dynamics



Reports a modelling study on long-term (20 years) impacts of present and alternative farming management practices on (SOC) dynamics.

the national farmlands are divided into six agricultural regions, based mainly on their agro-climate and cropping management conditions. A total of six representative farm fields were selected in regions respectively









Modeled 20-year SOC dynamics at the six sites Qiqihar (Northeast Region), Miyun (North Region), Pingliang (Northwest Region), Zhijinag (South Region), Jiangning (East Region) and Yanting (South west Region) under their baseline management conditions

Long-Term SOC Dynamics



- Under the present management conditions, the SOC status in the three northern sites where upland crops dominated appeared more dynamic than that in the three southern sites where paddy rice dominated.
- During the simulated 20 years, the northern sites were either losing or gaining SOC at relatively high rates from -1000 to 200 kg C/ha/yr; and the southern sites had relatively stable SOC contents with deviations ranging from -70 to 26 kg C/ha/yr.
- Increase in the fraction of above-ground crop residue incorporated in soil or application of manure effectively converted most of the tested sites into sinks of atmospheric carbon

 Ligang Wang, Jianjun Qiu*, Huajun Tang, Hu Li, Changsheng Li, Eric Van Ranst. Modeling soil organic carbon dynamics in the major agricultural regions of China. *Geoderma*, 147(2008): 47-55. (corresponding author)

Modeling N₂O emissions: Spring maize



- Results from the simulations indicated that management practices such as no-tillage, changing the time and rate of fertilizer application, increasing the rate of residue returned can effectively reduce N₂O emissions from the spring maize fields
- Li Hu, Qiu Jianjun, Wang LiGang. Estimates of N₂O emissions and mitigation potential from a spring maize field based on DNDC model. *Journal of integrative Agriculture*, 2012, 11(12): 2067-2078

Modeling analysis of contribution of root respiration to soil total respiration



According to the DNDC simulated results:

- 1. The contribution of maize root respiration to soil respiration at the whole growth stage varied from 91% to 93%,
- 2. while the contributions of cotton and wheat root respiration were 70% and 80%, respectively.
- 3. Soil N-application influenced not only soil microbial respiration but also root respiration.

 Li Hu, Qiu Jianjun, Wang Ligang. Characterization of Cropland Soil Respiration and Modeling Analysis on Contribution of Root Respiration [J]. *Transactions of the CSAE*, 2008,24(4): 14-20.



Application studies with DNDC

Modeling Impacts of SOC on Crop Yields and GHGs in China





Quantifying impacts of different SOC contents on crop yields in different croplands in China



Modeling SOC on Crop Yields

- If initial SOC content in cropland increased by 1 g C/kg, the crop yield could increase by:
 - 176 kg/ha for maize in the Northeast region,
 - 454 kg/ha for a maize and wheat rotation in the North region,
 - 328 kg/ha for maize in the Northwest region,
 - 185 kg/ha for single-rice in the Mid-south region,
 - 266 kg/ha for double- rice in East region, and
 - 229 kg/ha for rice and wheat rotation in Southwest region.
- There is a great potential for enhancing crop yield by improving SOC content in each region of China.
- Qiu Jianjun, Wang Ligang, Li Hu, Tang Huajun, Li Changsheng, Eric Van Ranst. Modeling Impacts of Soil Organic Carbon Content on Crop Yields in Croplands of China. *Chinese Agricultural Sciences*, 2009, 8(4):101-105

Modeling impacts of alternative farming practices on SOC and GHGs



C sequestration and GHG mitigation

 it is crucial to assess impacts of C-sequestration strategies on not only CO₂ but also N₂O and CH₄ emissions from the agricultural fields subject to the new farming management practices.

Modeling Tests with Alternative Scenarios



- 1. BASE: Conventional management practices.
- ALTER-1: Adopting the baseline scenario but with elevated rate of above-ground crop residue incorporation from 15% to 50% and amendment of 1000 kg C ha⁻¹ yr⁻¹ of farmyard manure for each of the six sites.
- **3.** ALTER-2: Adopting ALTER-1 but with an adjusted synthetic fertilizer application rate reduced by 50 kg N yr⁻¹
- 4. For each of 6 sites, DNDC was run first with the BASE scenario for 20 years; and in year 21 DNDC was continuously run with the BASE, ALTER-1 and ALTER-2 scenarios in parallel for 50 years.









The modeled data further indicated that reducing fertilizer application rates could not only decrease GHGs emissions but also benefit more environmental issues such as nitrate leaching while maintaining the optimum yields.

	Crop Yield (kg C ha ⁻¹ a ⁻¹)			Leached Nitrate (kg N ha ⁻¹ a ⁻¹)		
Cropping System Scenario ^a	BASE	ALTER-1	ALTER-2	BASE	ALTER-1	ALTER-2
QQ	2102	2102	2100	5.7	10.2	6.9
QZ	2347	2347	2347	158.5	205.0	177.0
PL	1643	2614	2480	1.3	3.3	2.7
JN	5679	5679	5678	113.1	183.1	128.4
ZJ	1866	2508	2120	10.5	41.2	21.2
YT	3416	3416	3416	130.8	202.8	158.0



- When the alternative management practices were employed C sequestration rates increased, however, N₂O or CH₄
 emissions were also increased for these practices;
- Reducing the application rates of synthetic fertilizer in conjunction with the alternative practices could decrease N₂O emissions while maintaining crop yields and C sequestration rates .
- The modeled results can serve for C sequestration and GHGs mitigation in agroecosystems of China.
- Qiu, J., C. Li, L. Wang, H. Tang, H. Li, and E. Van Ranst. 2009. Modeling impacts of carbon sequestration on net greenhouse gas emissions from agricultural soils in China. *Global Biogeochem. Cycles*, 23, GB1007, doi:10.1029/2008GB003180.



Modeling impacts of management practices on GHGs emissions

Mitigating GHG Emissions from Maize and Wheat Systems





The validated DNDC was then used for predicting impacts of three management alternatives (i.e., no-till, increased crop residue incorporation and reduced fertilizer application rate) on CO₂ and N₂O emissions from the target field. Finally, five 50-year scenarios were simulated with DNDC to predict their long-term impacts on crop yield, soil C dynamics, nitrate leaching losses, and N₂O emissions.

Mitigating GHG Emissions from Maize and Wheat Systems



Comparison of observed (filled circles) and simulated (solid line) of CO₂ and N₂O emissions in wheat/maize rotation fields: (a) and (c) the control treatment and (b) and (d) the fertilized treatment (Filled arrow: time of fertilization; open arrow: time of irrigation; dashed error bars are standard deviations for 3 repetition.)

Modeling managements on GHGs emission



4500 N fertilizer inputs 360 kg ha⁻¹ N fertilizer inputs 150kg ha⁻¹ 3000 GWP (kg C Ω equivalent ha⁻¹y⁻¹) 1500 0 11 16 21 31 36 26 -1500 Year Baseline -3000 Manure amendment 2000 kg C ha⁻¹ -4500 Residue return 100% -6000 -7500

Impacts of management practices on long-term N_2O fluxes

Impacts of management practices on longterm net greenhouse gas emissions

The modelled results suggested that implementation of manure amendment or crop residue incorporation instead of increased fertilizer application rates would more efficiently mitigate GHG emissions from the tested agro-ecosystem.

Hu Li, Jianjun Qiu, Ligang Wang, et al. 2010. Modelling impacts of alternative farming management practices on greenhouse gas emissions from a Winter Wheat-Maize rotation system in China. Agriculture, Ecosystem and Environment, 135(2010): 24-33.



Regional inventory of SOC, GHGs, Nbalance, N-leaching etc.

Regional inventory: SOC storage





DNDC estimated soil C fluxes and net C balance in cropland of mainland China in 1998. Total area of cropland in China was about 0.968×108ha in 1998, on which 2172.6×104 tons of fertilizer with pure nitrogen were applied annually. the total SOC storage in croplands in China is about 3968 Tg C; and SOC is lost at a rate of 78.89 Tg C/year. The highest losses of SOC occur in the northeastern provinces.

 Huajun Tang, Jianjun Qiu, Eric Van Ranst, Changsheng Li. 2006.
 Estimations of soil organic carbon storage in cropland of China based on DNDC model. *Geoderma*, 134: 200-206.

Regional inventory: SOC storage



The simulated results showed that the total SOC storage in the top layer (0-30 cm) of the 1.18×10^8 ha croplands of China is 4.7-5.2 Pg C in 2003 with an average value of 4.95 Pg C.

SOC density ranges from 3.9 to 4.4 kg C /m2, with an average of 4.2 kg C /m2, a level is much lower than the world average level.

Tang Huajun, Qiu Jianjun, Wang Ligang, Li Hu, Li Changsheng, Eric Van Ranst. Modelling soil organic carbon storage and its dynamics in croplands of China. *Chinese Agricultural Sciences*, 2010, 9(5):704-712

Regional inventory: GHGs



- In China, midseason drainage, which results in substantial reductions in total growing season CH4 fluxes, began to be implemented in wetland rice agriculture in the early 1980s, and has gradually replaced continuous flooding in much of the paddy rice area.
- We constructed a regional prediction for China's rice paddy methane emissions using the DNDC biogeochemical model.

Rice CH4 Emissions Decreased along with Increase in Midseason Driange in China from 1908s to 2000s





Results of continuous flooding and midseason drainage water management simulations for all paddy rice fields in China were combined with regional scenarios for the timing of the transition from continuous flooding to predominantly mid-season drainage to generate estimates of total methane flux for 1980, 1985, 1990, 1995, and 2000.

The results indicate that CH₄ emissions from China's paddy fields were reduced from 1980-2000 by about 5 Tg CH₄/yr.

Li, C., J. Qiu, S. Frolking, et al. 2002. Reduced methane emissions from large scale changes in water management of China's rice paddies during 1980–2000, *Geophysical Research Letters*, 29(20), 1972, doi:10.1029/2002GL015370.

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Regional inventory: N balance



 Qiu Jianjun, Li Hu, Wang Ligang. Simulation of nitrogen level and balance in cropland in China [J]. *Transactions of the CSAE*, 2008, 24(8): 40-44.

Regional inventory: N leaching



 Qiu Jianjun, Li Hu, Wang Ligang, et al. GIS-Model Based Estimation of Nitrogen Leaching from Croplands of China. Nutrient Cycling in Agroecosystems, 2011, 90(2):243-252

Modeled N Balance at National Scale



- N loss through leaching has been recognized as one of the most common agricultural sources of groundwater contamination.
- The spatial distribution of N leaching in China showed a sharp discrepancy between the northern and southern counties due to the differences in climatic conditions, soil properties, as well as farm management practices.

 Qiu Jianjun, Li Hu, Wang Ligang, et al. GIS-Model Based Estimation of Nitrogen Leaching from Croplands of China. *Nutrient Cycling in Agroecosystems*, 2011, 90(2):243-252

Regional inventory:

To establish the methodology with DNDC on quantified evaluating and monitoring agri. non-point pollution (C/N cycling) at watershed scale







Spatial Database for Upscaling





C balance of agro-ecosystem in Xiaoginghe watershed







Fertilizer application

Total N lossing

■ Gao Maofang, Qiu Jianjun, Li Changsheng, et al. Modelling nitrogen pollution from livestock breeding using Manure-DNDC model[J]. *Transactions of the Chinese Society of Agricultural Engineering* 2012, 28(9): 183−189.

Maofang Gao, Jianjun Qiu, Changsheng Li, Ligang Wang, Hu Li, Chunyu Gao. Modeling nitrogen loading from a watershed consisting of cropland and livestock farms in China using Manure-DNDC. 2012, (under review)





A book published by Science Press:

Quantified evaluation and controlling technology on C & N balance of agroecosystem in the region of Bohai Bay.

Thank you for your attention

qiujianjun@caas.cn